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Experimental Investigation of Concrete Properties on Partial Replacement of Aggregates with Waste Materials

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ABSTRACT

The paper presents an experimental investigation out to evaluate the mechanical properties of concrete mixtures in which fine aggregate (sand) was replaced with Copper Slag (CS) while coarse aggregates were replaced by recycled concrete aggregate (RCA) from a demolished structure. Both the fine and coarse aggregate were replaced by 10%, 20%, 30%, of CS and RCA by weight from

the control mixture (concrete mix with 0% of CS and/or RCA). Tests were performed for properties of fresh concrete and hardened concrete. Slump test was conducted to determine the workability of the various design concrete mix. Compressive strength and split tensile strength were determined at 7 and 28 days of curing. The results indicate that workability decreases slightly with an increase in Copper Slag percentage, though workability for the samples is within the prescribed limit for M25 concrete. The results indicate a considerable improvement in the strength properties of the plain concrete by the inclusion of CS alone while a reverse trend is observed for the increasing percentage of RCA. The synergistic effect of CS and RCA on the designed sample concrete revealed that the percentage of CS is the more decisive factors than the percentage of RCA in deciding the performance of the concrete in terms of strength. The optimum percentage of Copper slag is 30 % and 10 % for recycled coarse aggregates in terms of both compressive and tensile strength. It affirms that CS and RCA can be effectively used in structural concrete as a replacement of fine aggregate (sand) and coarse aggregate respectively. It further substantiates towards sustainable construction approach because of its dual advantage of controlling the menace of solid waste disposal, increasing the cost efficiency and carbon efficiency of the product.

Keywords: Copper Slag, Recycled aggregate, Concrete, Workability, Compressive strength, tensile strength

1. INTRODUCTION

The concurrent scenario of increased population, rapid growth in industrialization resulted in a generation of huge amount of solid waste. It has caused substantial damage to natural resources and the environment (Prem et al. 2018). These solid wastes have also caused serious concern from the point of its transportation and safe disposal as it may cause environmental contamination and need ever diminishing costly land. At the same time, the construction industry has been growing rapidly and also witnessing a shortage of raw construction material to meet out its demand (Sharma and Khan 2018). The depleting natural resources accompanied by increasing solid waste from industry invoked the concept of sustainability in the construction industry. It involves the use of nonconventional and innovative materials including recycled waste materials (Shubhendu and Sharma 2018).

This has opened a new avenue of research and utilize the various solid waste generated from different industries. One of such solid waste is Copper Slag (CS) and another one is Recycled Concrete Aggregate (RCA) from demolished structures which have brought the attention of civil engineers, professionals from the construction industry and environmental scientists (Al-Jabri et al., 2011; Bajad 2015; Dash et al., 2016). Copper slag is a waste materials obtained during the flotation stage of the copper extraction process. It is estimated that for every one ton of copper produced; around 128 tons of solid copper slag is generated (Gordon 2002). The worldwide production of copper slag stands at 33 Million tons and out of which around 6.0–6.5 million tons is generated in India alone (Mithun and Narasimhan, 2018). Some of the potential applications of CS are asphalt pavements, railroad ballast, road-base construction, cement manufacturing, tiles, glass, abrasive tools, cutting tools, and roofing granules (Shi et al., 2008; Onuaguluchi and Eren 2012; Dhir et al., 2017). However, this is not sufficient and most of CS takes its way to land filling and/or solid disposal site. The recycled concrete aggregate (RCA) witnesses a similar fate. Thus, its usability in concrete could be another potential area which helps to curb the problem of disposal of CS and RCA (Al-Jabri et al., 2009; Ambily et al,. 2015; El-Hassan et al., 2019). This option offers huge potential as concrete is the most widely used material in the world. The CS can be used as a replacement of fine aggregate (sand) while RCA can replace coarse aggregate in the conventional concrete mix. It invoked a large number of researchers to investigate the possibility of using CS and RCA in concrete for a given specific use (Gupta and Siddique 2019; Mahesh Babu and Ravitheja 2019; Saravanakumar et al., 2016; Singh and Singh 2019; Wu et al., 2010). However, it could alter some of the important properties of the concrete required for a specific purpose. It triggered researchers to explore the effect of CS and RCA on the mechanical properties of pervious concrete (Lori et al., 2019), self compacting concrete (Sharma and Khan 2018) and high performance concrete (Al-Jabri et al., 2009; Chithra et al., 2016; Edwin et al., 2016; Khanzadi and Behnood 2009). The mechanical properties like strength and durability along with workability of the concrete are important parameters that got considerations in these studies. It is because very often these properties of concrete vary considerably during experimental investigation depending upon the quality of locally available raw materials including water and climatic conditions.

Keeping in view the above facts, the present study is an attempt to study the possibility of using copper slag as a substitute of fine aggregates (sand) and recycled concrete aggregate as a substitute for coarse aggregate in preparation of fresh concrete of a specific grade. The main objective of this work is to design M25 concrete as per IS code and also with partial replacement fine aggregate (sand) with copper slag (CS) and coarse aggregate with recycled concrete aggregate (RCA) at varying proportion at an increment of 10%. It has also an objective to determine the property of the fresh concrete (workability – slump), hardened concrete (compressive and split tensile strength) at 7-days and 28-days of curing with respect to control concrete.

2. MATERIALS AND METHODS

The experimental works involve the preparation of design mix M25 without and with CS and RCA with different proportion of these waste materials as per the prescribed standard (BIS 2009). The various materials used in designing of mix concrete along with their characteristics are presented as below:

Materials

a. Cement

Cement is a material used in construction which solidifies, sets, and holds fast other varying materials to bond with them altogether. It mixes with fine aggregates to produce brick work mortar or with rock and sand to produces concrete. OPC of grade 43 is used in this study which following characteristics compared to prescribed standard (BIS 2013):

Table 1: Test results of Cement Sample

S. No	Characteristics	Experimental value	Requirements as per IS: 8112-1989
1.	Consistency (%)	28	-
2.	Specific gravity (g/cc)	3.15	3.15
3.	Initial setting Time (min)	93	>30
4.	Final setting Time (min)	210	<600
5.	Fineness (%)	6	10%
6.	Soundness (mm)	2.56	<10 mm

b. Sand

Locally available river sand sieved through 4.759mm sieve was used as fine aggregates to meet the requirement of zone IV as per IS: 383-1970 (BIS 1970). The characteristics of the sand are as below:

Table 2: Fine Aggregate Properties

S. No	Characteristics	Values
1.	Specific gravity	2.64
2.	Moisture Content	0.19 %
3.	Total water absorption	1.23 %
4.	Net water absorption	0.84 %
5.	Fineness modulus	2.567

Table 3: Coarse Aggregates Properties

Sr.No	Particulars	Properties
1.	Type	Crushed
2.	Maximum Size	20 mm
3.	Specific gravity (10 mm)	2.765

4.	Specific gravity (20 mm)	2.894
5.	Total water absorption (10 mm)	1.5937 %
6.	Total9water absorption (20 mm)	3.586%
7.	Moisture content (10 mm)	0.874 %
8.	Moisture content (20 mm)	0.7235 %
9.	Fineness Modulus (10 mm)	6.38
10.	Fineness Modulus (20 mm)	7.54

c. Coarse Aggregates

Coarse Aggregates are latent granular9materials obtained from crushing locally available stone, rock. It acts as inactive filler inside the concrete mix and constitutes 60% to 80% by volume of concrete. The properties of coarse aggregate used here are as below which satisfied the prescribed requirements (BIS 1987):

d. Water

Water is essentially needed for facilitating the hydration of concrete and also to provide desired blending and setting properties in concrete. In this study, consumable tap water was utilized for the concrete mix preparation and curing of moulds of the concrete sample as well. The pH of water is estimated to be 7.1.

e. Copper Slag

Copper slag is a type of blasting grind formed from granulated slag from metal smelting processes. It is collected from S.S Traders, Jalandhar, India. The physical properties of the copper slag are shown in Table 4.

Table 4: Copper slag Properties

Sr. No	Properties	Parameters
1.	Specific Gravity	3.83 gm/cm^3
2.	Bulk Density	2.08 g/cc
3.	Electric Conductivity	4.8
4.	Particle Size	0.2 - 3.0 mm
5.	Shape of Particle	Irregular shape
6.	Plausibility	Glassy & Black
7.	Voids	42 %
8.	Chloride Content	< 0.0002 %

The chemical composition is predominantly includes Fe_2O_3 (68.29%), SiO_2 (21.13%) and insoluble Residue (14.87%) besides CuO (1.20%), Na_2O (0.58%), TiO_2 (0.41%) etc.

f. Recycled Concrete Aggregates (RCA)

The source of concrete used for the preparation of RCA is old broken concrete cube/beam removed from Concrete testing Lab after performing the experiments in regular classes. Aggregates are obtained by crushing the cube into smaller chunks according to the desired aggregate size in Machine Jaw Crusher.

Experimental Design

The concrete mix design of M25 grade (normal concrete - control) was prepared according to IS 10262-2009 specifications (BIS 2009). A blend ratio of cement: sand: coarse aggregate used was 1:1.49:2.58 with a water-cement ratio of 0.45 and super-plasticizer of 0.75%.

In order to investigate the effect of copper slag (CS) and recycled concrete aggregate (RCA) on the strength of normal concrete, various concrete mixtures with different proportions of CS and RCA as a partial substitute (proportion by weight) for fine aggregates and coarse aggregate respectively were prepared with a target 28 day compressive strength of 25 MPa (N/mm^2). The mix proportion chosen for this study is given in Table 5.

Table 5: Mix Proportion of Concrete cubes

Designation	Mix	Water (kg/m^3)	Cement (kg/m^3)	Fine Agg. (Sand) (kg/m^3)	Copper slag (kg/m^3)	Coarse Agg (kg/m^3)	Recycled Aggregates (kg/m^3)
M-0	Normal	197	437.78	654	--	1133	--
M-1	10 % CS	197	437.78	588.6	65.4	1133	--
M-2	20 % CS	197	437.78	523.2	130.8	1133	--
M-3	30 % CS	197	437.78	457.8	196.2	1133	--
M-4	10 % RCA	197	437.78	654	--	1019.7	113.3
M-5	20 % RCA	197	437.78	654	--	906.4	226.6
M-6	30 % RCA	197	437.78	654	--	793.1	339.9
M-7	10 % CS 10 % RCA	197	437.78	588.6	65.4	1019.7	113.3
M-8	10 % CS 20 % RCA	197	437.78	588.6	65.4	906.4	226.6
M-9	10 % CS 30 % RCA	197	437.78	588.6	65.4	793.1	339.9
M-10	20 % CS 10 % RCA	197	437.78	523.2	130.8	1019.7	113.3
M-11	20 % CS 20 % RCA	197	437.78	523.2	130.8	906.4	226.6
M-12	20 % CS 30 % RCA	197	437.78	523.2	130.8	793.1	339.9
M-13	30 % CS 10 % RCA	197	437.78	457.8	196.2	1019.7	113.3
M-14	30 % CS 20 % RCA	197	437.78	457.8	196.2	906.4	226.6
M-15	30 % CS 30 % RCA	197	437.78	457.8	196.2	793.1	339.9

The various tests on fresh concrete and hardened concrete were performed. Workability was estimated using the slump cone test as per the code IS code (BIS 1959). Cubes of size 150mm × 150mm × 150mm were cast and tested for compressive strength and split tensile strength. The tamping method which involves filling of the moulds in three layers, tamping each layer 25 times followed by tamping the sides of the mould 10 times. Then the concrete mix samples were allowed to harden in the moulds for 24 hrs and then removed from their moulds. Then the prepared concrete mix samples were placed in curing tank having water at a temperature of 26 ± 2°C. The sample cubes were taken out after 7-days and 28-days of curing periods to determine the compressive strength and tensile strength as per guidelines prescribed in standards (BIS 1959; BIS 2000). All these lab tests were conducted for a minimum of six samples of cube (three each for 7-days and 28-days of curing) of a given concrete mix (M0- M15) and their average values were noted down.

3. RESULTS AND DISCUSSIONS

The outcomes of the various tests on the designed concrete samples with copper slag (CS) and/or recycled aggregate (RCA) are presented in this section. Specifically, the results of workability and concrete strength are discussed. The concrete used here as a control specimen is M25 with water to cement ratio of 0.45.

Workability of Concrete

In general, high workability in concrete is desirable as it ensures full compaction (100%) needed to mix, handle, compact and mould concrete to any shape like plastic. In other words, workability or the plastic nature of fresh concrete is an important parameter to enable maximum strength for concrete. The workability of the concrete was measured in terms of the slump value in the present study. Figure 1 and Figure 2 show the effect of replacement of fine aggregate in concrete alone with Copper slag (CS) and recycled aggregate (RCA) only by 10 %, 20% and 30%.

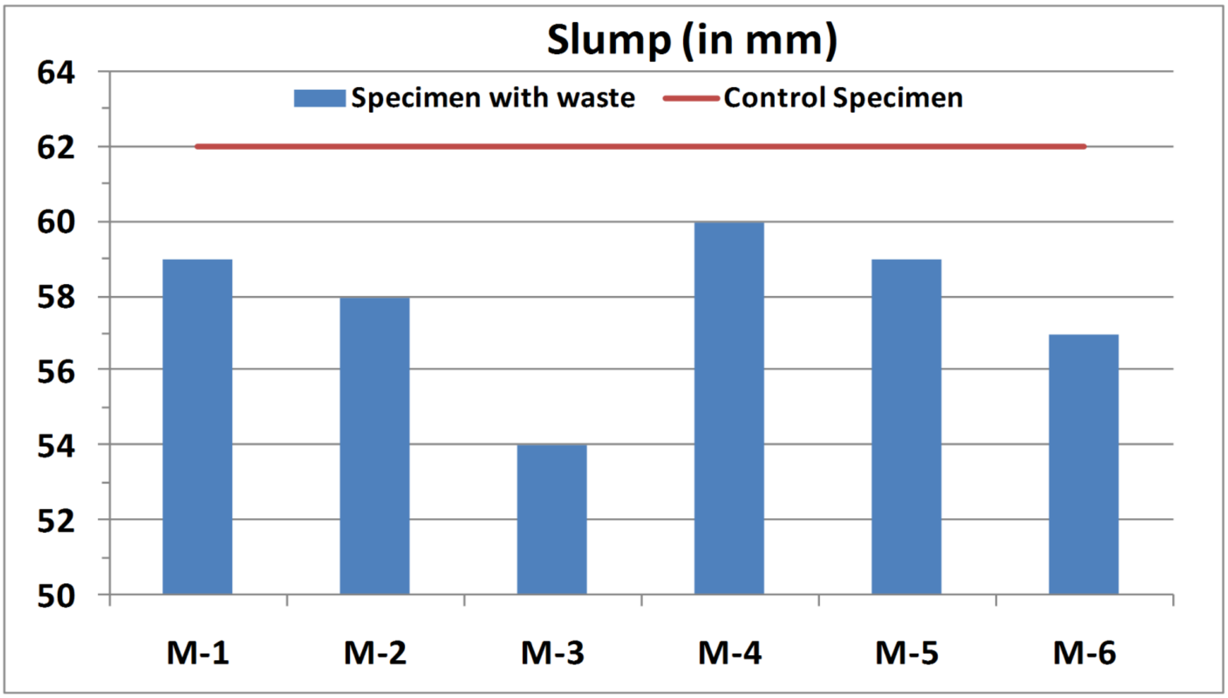

Figure 1: Workability of Concrete by using Copper Slag only (M-1 to M-3) and recycled aggregates only (M-4 to M-6)

Figure 1 shows that the slump of the various concrete mixes with copper slag only decreases with increasing CS contents in the design mix (M-1 to M-3). Similarly, the values of slump values for the concrete mix with only recycled aggregate (RCA) are also observed to be decreased with increasing content of RCA (M-4 to M-6). However, for a given percentage of replacement, conventional aggregate with CS or RCA (e.g. 10% or 20% or 30%), the slump values for the concrete mixes with RCA are higher compared to concrete mixes with CS. The might be because RCA absorbed a lesser amount of water compared to CS leaving behind sufficient water required for good slump value. However, the slump values in all the concrete mix design with the replacement of CS or RCA (M-1 to M-6) are less than the control mix (M-0). The decrease in slump values might be due to excessive absorption of water by the CS or mortar paste on the surface of RCA. Notably, all the samples studied above have the slump values well within the range described for M25 concrete with W/C ratio of 0.45 i.e. 50-75mm. Figure 2 depicts the workability of concrete in terms of slump values for the various proportion of CS and RCA in various concrete mixes (M-7 to M-15) as compared to control concrete mix (M-0).

It is observed that for a given percentage of CS (e.g. 10% or 20% or 30%), the slump values of concrete mixes decreases with the increasing proportion of RCA (10% to 30%) and also increase with the proportion of CS. Accordingly, the maximum and minimum values of the slump are observed for M-7 (CS 10% and RCA 10%) and M-15 (CS 30% and RCA 30%). On using the various proportions of CS and RCA the values of the slump (workability) decreased a little bit as compared to use of CS or RCA alone.

The slump values of M-9, M-12 and M-15 are less than the recommended value of slump ranges (50-75mm) for an M25 concrete with 0.45 water-cement ratio. In order to get the required workability of the concrete either water-cement ratio has to be increased or use of an additional amount of super-plasticizer is desirable. In case of replacement of coarse aggregate with RCA (M-4 to M-6) alone, the slump values are relatively higher than the concrete with CS alone for fine aggregate (M-1 to M-3). This has happened because of the large void space provided by the RCA and a lesser amount of water absorption as compared to CS. However, in case of combined use of CS and RCA with different proportion, the lower proportion of both CS and RCA is desirable to achieve the required slump. The slump test results indicate that the no additional amount of water is required in all the mixed design of concrete except (M-9. M-12 and M-15) which agree with earlier findings Dash et al (2016). In contrast to previous findings (Al-Jabri et al. 2009b; Chithra et al. 2016), the slump values are found to be decreased in all the designed concrete mix (M-1 to M-15).

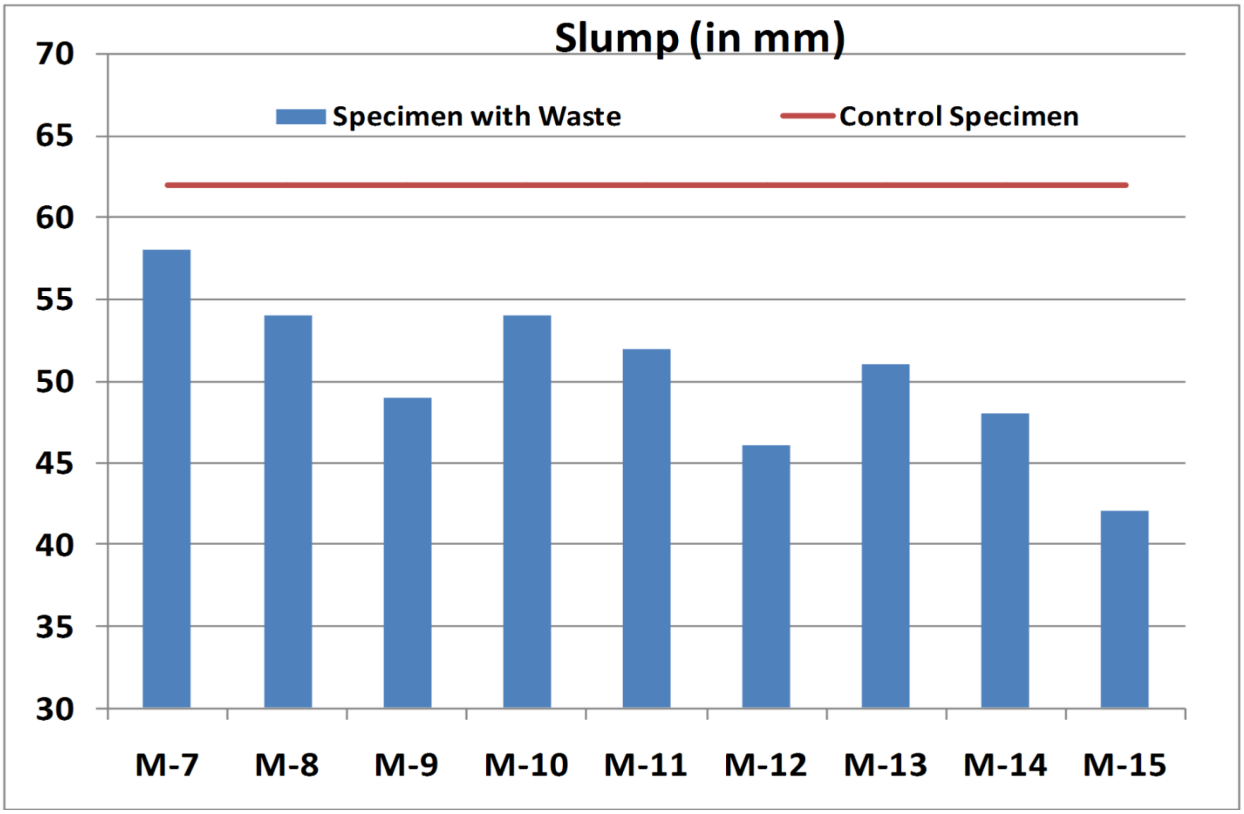

Figure 2: Workability of Concrete by using Copper Slag and Recycled Aggregates at Different Proportions

Figure 3 presents a surface plot showing the combined effect of copper slag as a replacement to fine aggregate (Sand) and RCA as a replacement to coarse aggregate on the workability of concrete.

It is obvious from the Figure 3 that above 15% of CS and RCA, the values of slumps fall drastically pointing out that if the proportion of CS and RCA increase beyond 15% induced stiffness in the concrete. This observation inferred that the concrete mix design with a maximum of 15% of CS and RCA exhibit acceptable workability required for easy handling, placement, and finishing. In such a situation, the augmentation of concrete with an extra amount of super-plasticizer is inevitable to maintain the desired workability. It is clear from Figure 3 shows that the workability of concrete decreases with an increasing proportion of CS and RCA content in concrete mixes. This observation contradicts with the observation reported by Al-Jabri (2009). However, the replacement of fine aggregate with CS and coarse aggregate with RCA help on reducing bleeding and segregation of the concrete.

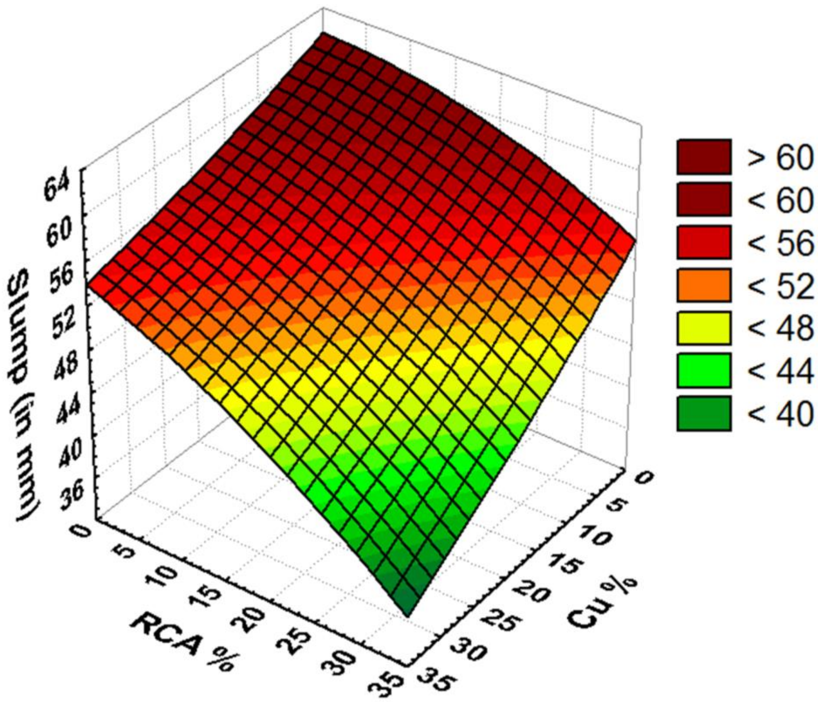

Figure 3: Impact on the Workability of Concrete at varying proportions of Copper Slag and Recycled Aggregates

Compressive Strength Test

The concrete strength depends on various aspects like the cement type, quality or proportion of copper slag, recycled aggregates and curing temperature. Compressive strength test1was performed confirming to IS1516-1959 to achieve the test results for concrete cured with water under controlled laboratory condition at the curing age of 7 and 28 days. Figure 4 and Figure 5 graphically display the effect of replacement of fine aggregate in concrete alone with Copper slag (CS) and replacement of coarse aggregate with recycled aggregate (RCA) only by 10%, 20% and 30%. It is clear from these figures that compressive strength of the studied concrete mixes continued to increase with the increasing age from 7-days to 28-days. The interesting observation is that after 28-days of curing all the concrete mixes able to attain the desired design strength of 25 MPa except only M-6 (design with 30% replacement of coarse aggregate with RCA).

Figure 4 shows that the compressive strength of the various concrete mixes with copper slag (CS) only increases with increasing CS contents in the design mix (M-1 to M-3). The compressive strength values of the designed mixes (M-1 to M-3) have higher values than the compressive strength of control design mix (M-0) measured after curing age of both 7-days and 28-days. The highest compressive strength (28-days) is achieved for M-3 (30% replacement of fine aggregate with CS) with a compressive strength value of 35.2 MPa compared to 28.2 MPa for the control concrete mix (M-0). This means that there is an increase in the strength of almost 25% compared to the control mix. Similarly, for these concrete-mix designs with CS, the maximum strength at 7-days is around 24% higher for M-3 than its corresponding value in the control mix (M-0). The observation is in agreement with report of previous researchers (Chithra et al. 2016; Rajasekar et al. 2019) while in opposed to observation of Mirhosseini et al. (2017) who reported a loss of compressive strength at this percentage of replacement of CS.

The types of coarse aggregate also affect the compressive strength relationship considerably. Figure 4 also shows that the values of compressive strength for the concrete design mixes with recycled aggregate (RCA) only decreases with the increasing content of RCA (M-4 to M-6). In contrast to CS, the design mixes of concretes prepared using RCA (M-4 to M-6) are invariably lower than the compressive strength of control design mix (M-0) measured after curing age of both 7-days and 28-days. The lowest compressive strength after 28-days of curing is observed for M-6 i.e. 30% replacement of coarse aggregate with RCA, which is found about 24.67 MPa which is almost 12.5% lower than the strength of the control mix. Similarly, the concrete mix M-6 exhibits the lowest compressive strength at 7-days of curing, which is around 12% less than its corresponding value for M-0. The observation further substantiates the findings of previous researchers (Vijayaraghavan et al. 2017; Saravanakumar and Dhinakaran 2012) who have also reported similar findings.

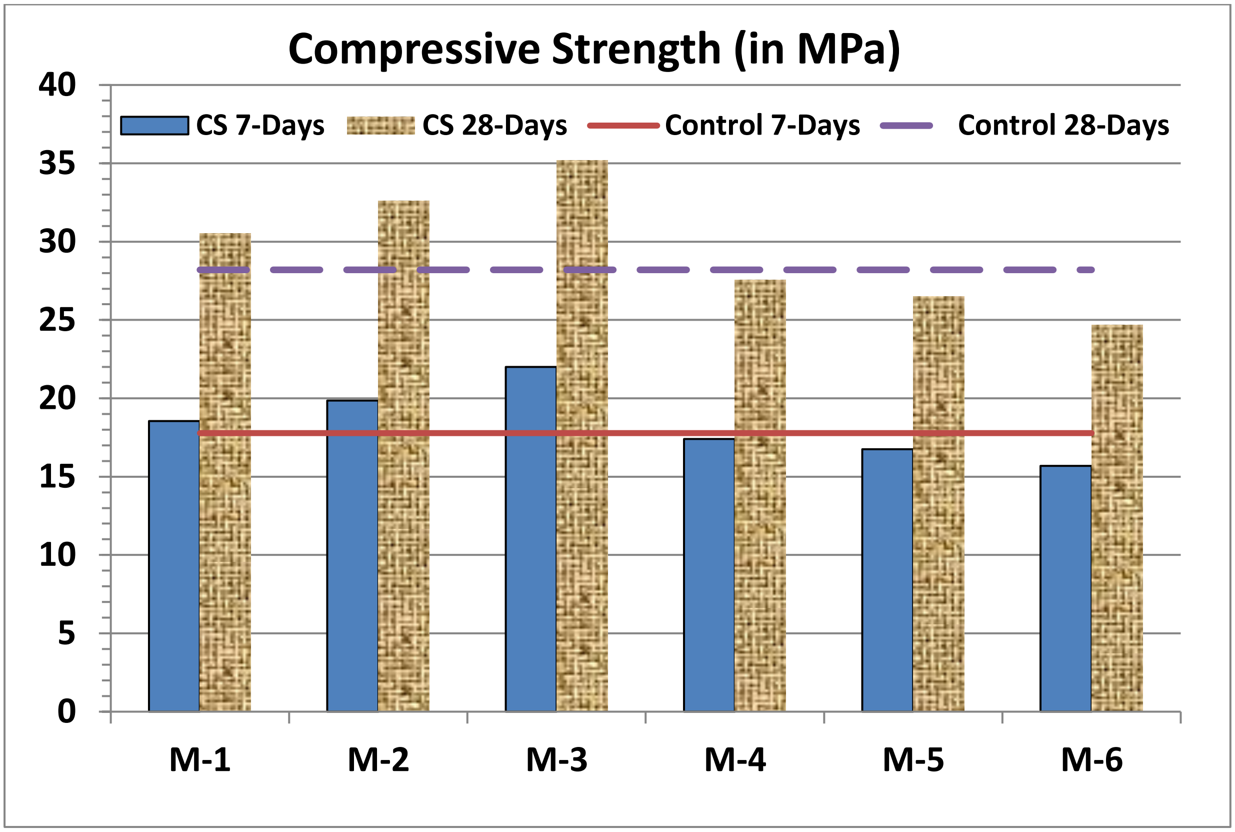

Figure 4: Compressive Strength of Concrete by using Copper Slag only (M-1 to M-3) and recycled aggregates only (M-4 to M-6)

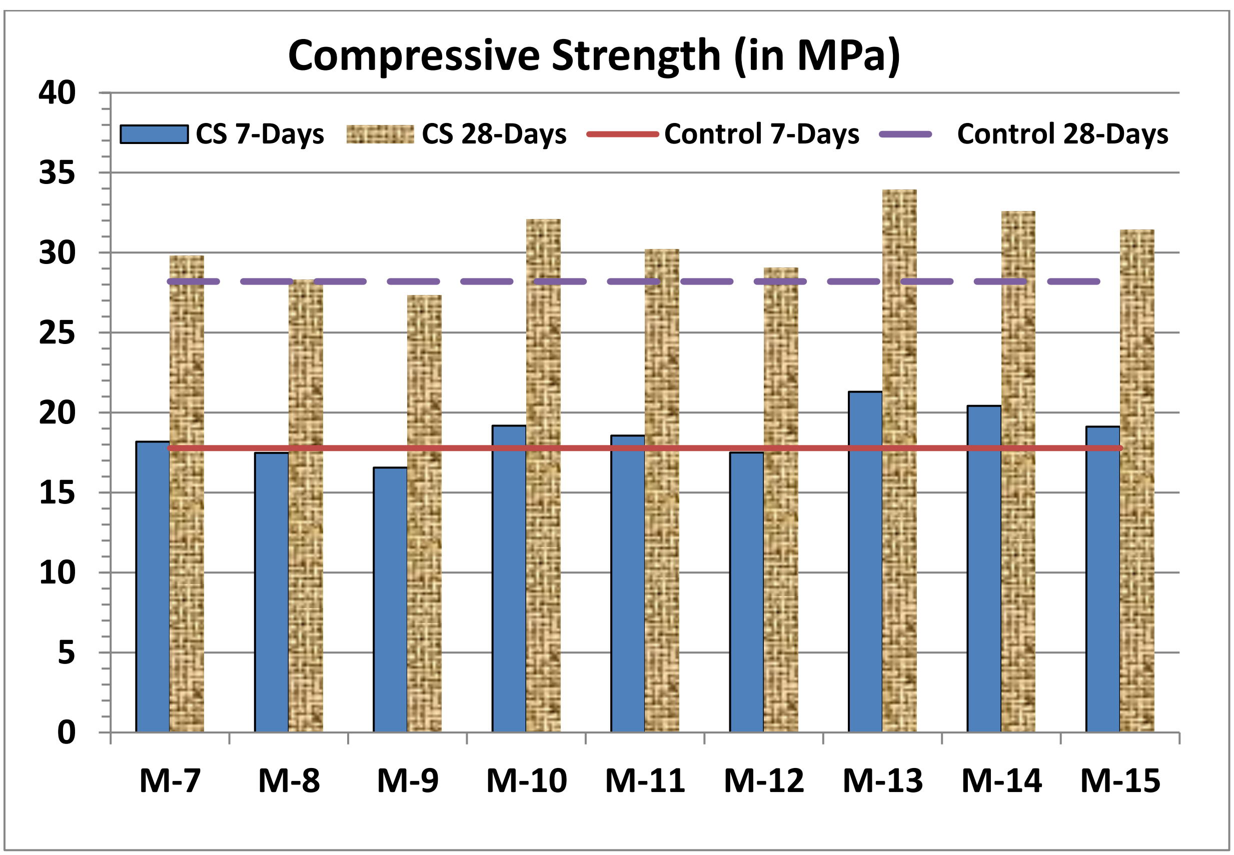

Figure 5: Compressive strength of Concrete by using Copper Slag and Recycled Aggregates at Different Proportions

Figure 5 presents the compressive strength of the various concrete design mixes (M-7 to M-15) prepared using various percentage combinations of CS and RCA compared to the compressive strength of control concrete mix (M-0) at both the curing ages of 7-days and 28-days. The figure shows that there is a significant increase in compressive strength of the concrete design mixes (M-7 to M-15) from 7-days to 28-days. It is clear from the fact that after 7-days the values of compressive strength of three samples (M-8, M-9 and M-12) are lower than the control mix but after 28-days only one (M-9, 10% CS + 30% RCA) is lower than the control mix. However, all the design mixes are able to achieve compressive strength more than the design strength of 25MPa.

The concrete mix M-13 (M-13 (30% CS + 10% RCA) exhibit the maximum values of compressive strength at all stages irrespective of the curing age. After curing age of 7-days and 28-days it exhibits a compressive strength of 21.30 MPa and 31.45 MPa respectively. These values are over 17.78% and 30.45% from the control concrete (M-0) after 7-days and 28-days of curing, respectively. Mirhosseini et al. (2017) also found that replacement of CS as fins aggregate in concrete by 30% gives optimum results in terms of compressive strength. In contrast, the values of compressive strength are least for M-9 (10% CS + 30% RCA) at different curing age. It exhibits a compressive strength of 16.57 MPa and 27.35 MPa after curing age of 7-days and 28-days, respectively. These values are in a shortage of 15.57% and 01.35% from the control concrete (M-0) after 7-days and 28-days of curing, respectively. The above discussion points that the designed concrete mix with CS and RCA may be inferior to control concrete for works required an early setting of concrete, but it can be used effectively for works of medium to long duration setting time.

Figure 6 and Figure 7 display the combined effect of copper slag as a replacement to fine aggregate (Sand) and RCA as a replacement to coarse aggregate on the compressive strength of concrete after 7-days and 28-days of curing age as surfaces, respectively.

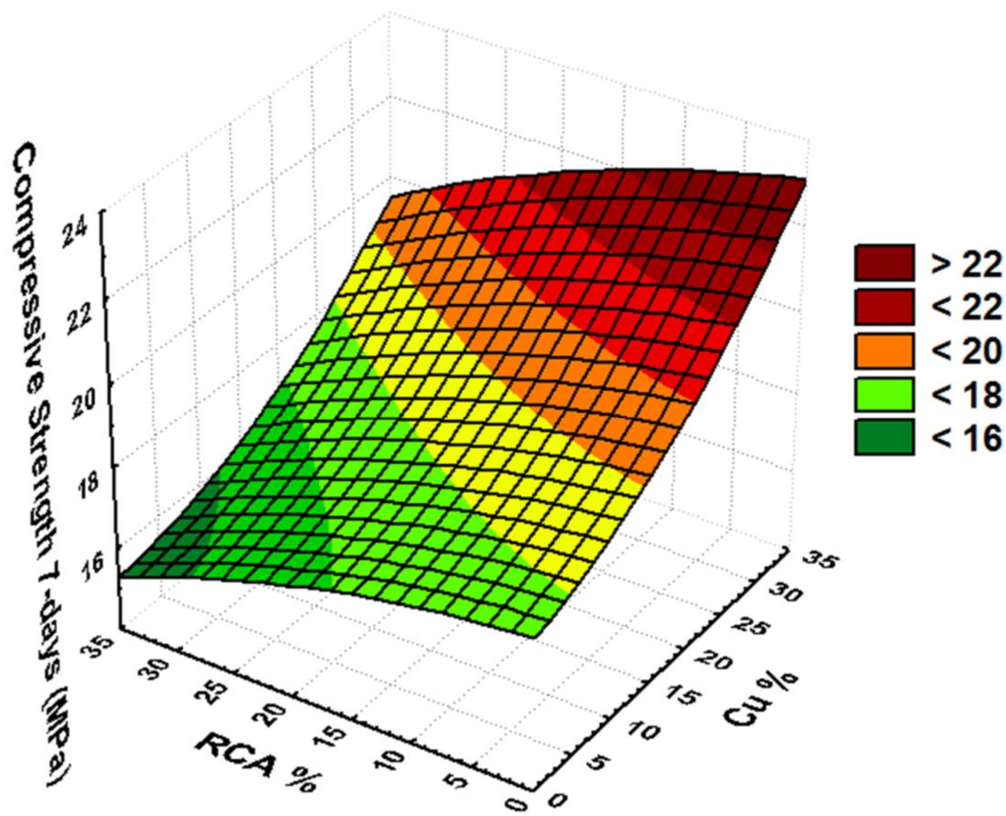

Figure 6: Impact on Compressive strength (7-days) of Concrete at varying proportions of CS and RCA

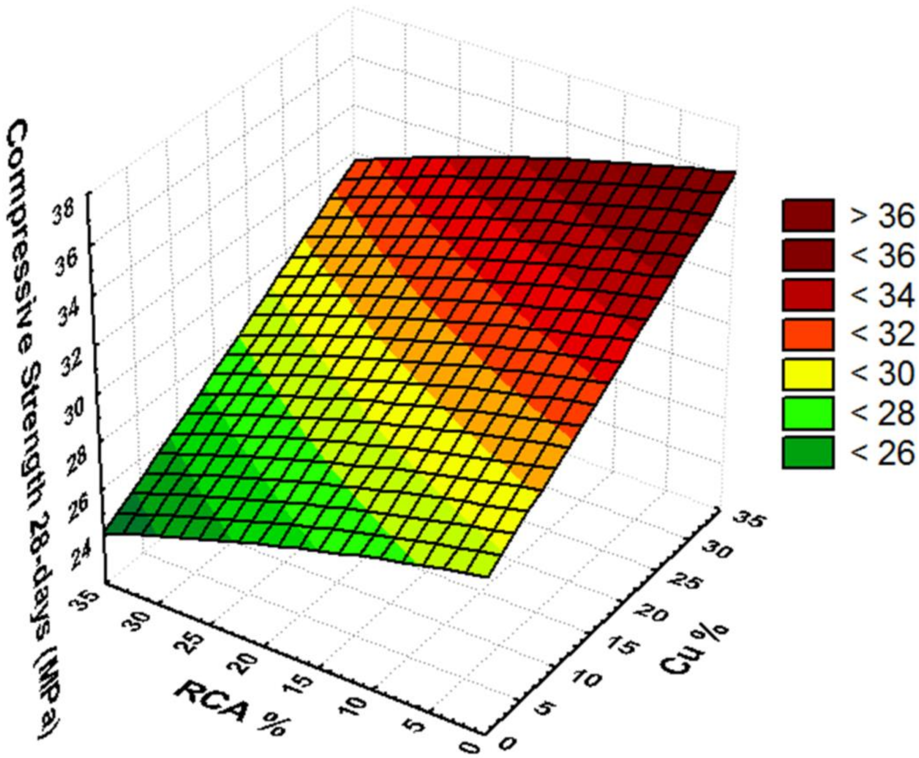

Figure 7: Impact on Compressive strength (28-days) of Concrete at varying proportions of CS and RCA

Figure 6 points out that there is variation in compressive strength of designed concrete mixes with percentage variations in CS and RCA after 7-days of curing. There observed a sharp increase in CS beyond 15% and decrease in RCA beyond 20%. For compressive strength after 28-days of curing, the trend is similar. However, it is gradual in contrast to sharp for 7-days (Figure 7). Comparison of the two figures reveals that a retarded development of compressive strength value at early ages (7 days) and an accelerated growth at later ages (28 days). These observations are much similar to the results of some previous researchers (Al-Jabri et al. 2009; Lori et al. 2019; Singh and Singh 2019). However, because of the above reason the concrete blended with CS and RCA cannot be used for fast track construction projects

Figure 6 and Figure 7 reveal that for a given percentage of replacement of fine aggregate with CS, the value of compressive strength of the concrete design mix decrease with the increase in the percentage of RCA. From the above observation, it discloses the fact that for a concrete mix with both CS and RCA, a high percentage of CS is the more decisive factor for getting the higher compressive strength.

The reason for the increase in compressive strength with the increasing percentage of CS is that copper slag also has pozzolanic properties because of the presence of oxides such as CaO, $Al2O_3$, SiO_2, and Fe_2O_3. All these minerals of oxide under activation with NaOH show a cementitious property. Another reason could be the fact that CS because of its fine size fills the gap in concrete compactly. The retardation in compressive strength of concrete mixed blended with RCA is because of several reasons. The foremost reasons could be the presence of adhered mortar in recycled aggregate (RCA) which forms weak bonding leading to the development of cracks in the concrete. Moreover, the possibly large number of voids with an increasing percentage of RCA could weaker bonding between the RCA particles and cement and natural aggregate. Further, during curing, water may fill the voids which resulted in increased water absorption and decreased compressive strength (Saravanakumar and Dhinakaran 2012). In such a situation, the RCA should be chosen of recommended size and should be treated chemically for improving the physicochemical characteristics of RCA.

These results and the discussion thereof indicate that CS and RCA can be used around 20% as replacement to fine aggregate and coarse aggregate with confidence in concrete mixes.

Split Tensile Strength Test

The split tensile strength examination was performed on concrete cylinders of 300 mm length and 150 mm diameter after curing age of 7 days and 28 days Compression Testing Machine (CTM) as per the guidelines provided in IS 516-1959. Split tensile strength

expresses the ability of concrete to resist elongation or bending. The study used Split cylinder method to determine the tensile strength of concrete. Concrete is usually weak in tension. Theoretically, the tensile strength of concrete is 10 - 15% of compressive strength. Therefore, the tensile strength of M25 grade concrete shall be between 2.5–3.35 MPa. The results for tensile strength showed similar behaviour to the compressive strength.

Figure 8 and Figure 9 illustrate the effect of replacement of fine aggregate in concrete alone with Copper slag (CS) and replacement of coarse aggregate with recycled aggregate (RCA) only by 10%, 20% and 30%. It is obvious from these figures that tensile strength of all mixes continued to increase with the increasing age from 7-days to 28-days. The interesting observation is that even after 28-days of curing none the concrete mixes can attain the desired tensile strength of Control concrete mix 3.538 MPa. For most of the concrete mixes studied the average tensile strength was within the permissible values as per the design specifications.

Figure 8 shows that the tensile strength of the various concrete mixes with copper slag (CS) only increases with increasing CS contents in the design mix (M-1 to M-3) because of improved bonding between the cement and CS. But the tensile strength values of the designed mixes (M-1 to M-3) have lower values than the control design mix (M-0) measured after curing age of both 7-days and 28-days. The highest compressive strength (28-days) is achieved for M-3 i.e. 30% replacement of fine aggregate with CS, which is found to be 3.395 MPa compared to 3.538 MPa for the control concrete mix M-0). It is equivalent to a decline of the tensile strength of almost 4% compared to the control mix. Similarly, at 7-days of curing the reduction in M-3 is around 27.5% lower than its corresponding value in the control mix (M-0). These observations are partially agreed with the results reported by some of the previous researchers (Khanzadi and Behnood 2009; Rajasekar et al. 2019).

In contrast, the values of tensile strength for the concrete mix with recycled aggregate (RCA) only are observed to be decreased with the increasing content of RCA (M-4 to M-6). Moreover, the values of tensile strength for the concrete samples are invariably lower than the control concrete and concrete mix with CS only at a given percentage irrespective of the stage of curing.

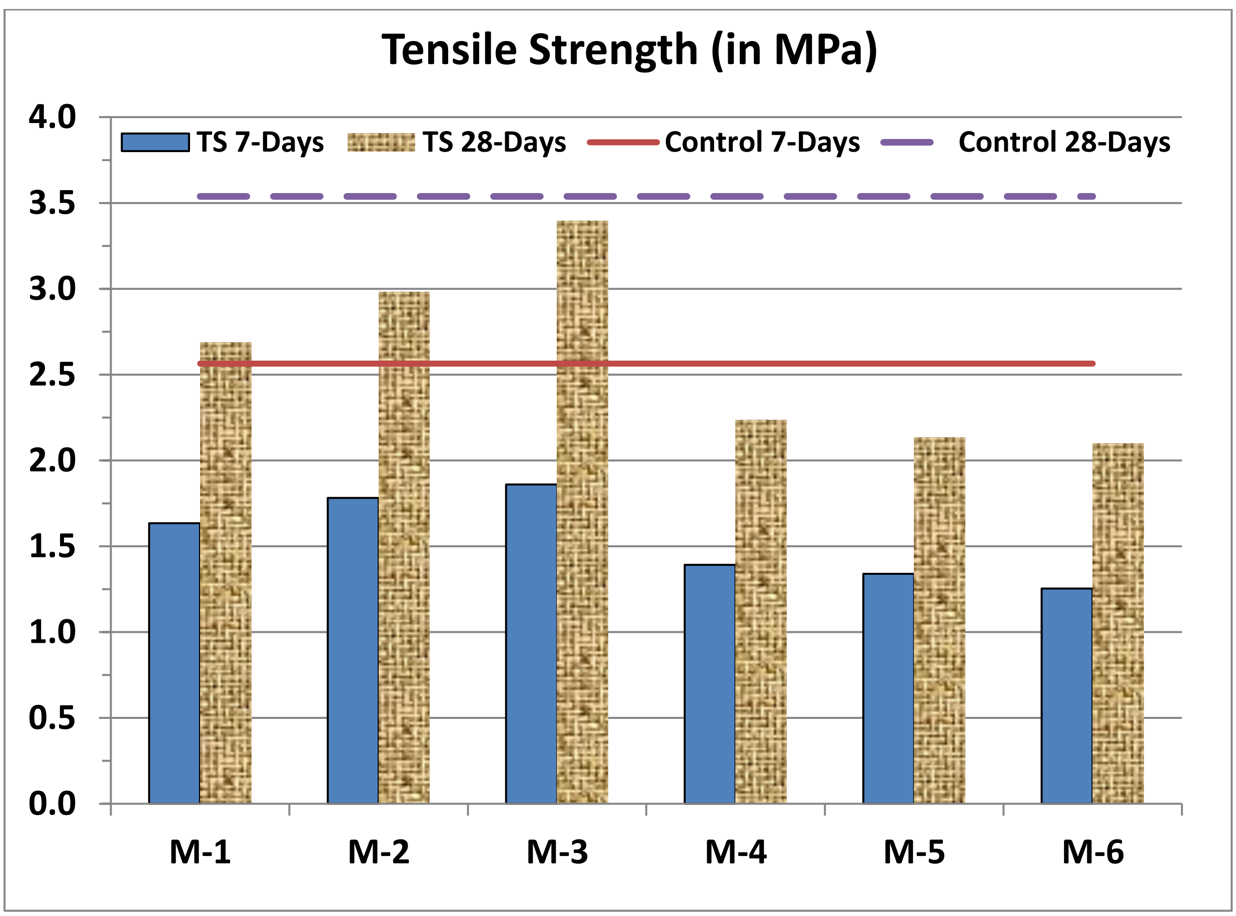

Figure 8: Tensile Strength of Concrete by using Copper Slag only (M-1 to M-3) and recycled aggregates only (M-4 to M-6)

Figure 9 presents the synergistic effect of various percentage combinations of CS and RCA on tensile strength of the studied concrete design mixes (M-7 to M-15) compared to the tensile strength of the control concrete mix (M-0) after 7-days and 28-days

of curing. The figure shows that there is a decline in the tensile strength of the concrete design mixes (M-7 to M-15) in all the curing stages. However, the highest values of tensile strength are found for M-13 (30% CS + 10% RCA) while M-9 (10% CS + 30% RCA) exhibited the lowest value at different curing ages. The above observation substantiates the fact that the designed concrete mix with CS and RCA may be inferior to control one but of reasonable strength at least for concrete mix M-10, M-13, M-14 and M-15. The lower values of tensile strength of concrete with CS and/or RCA as compared to the control concrete are lower which disagree with observation earlier researchers (Rajasekar et al. 2019; Wu et al. 2010).

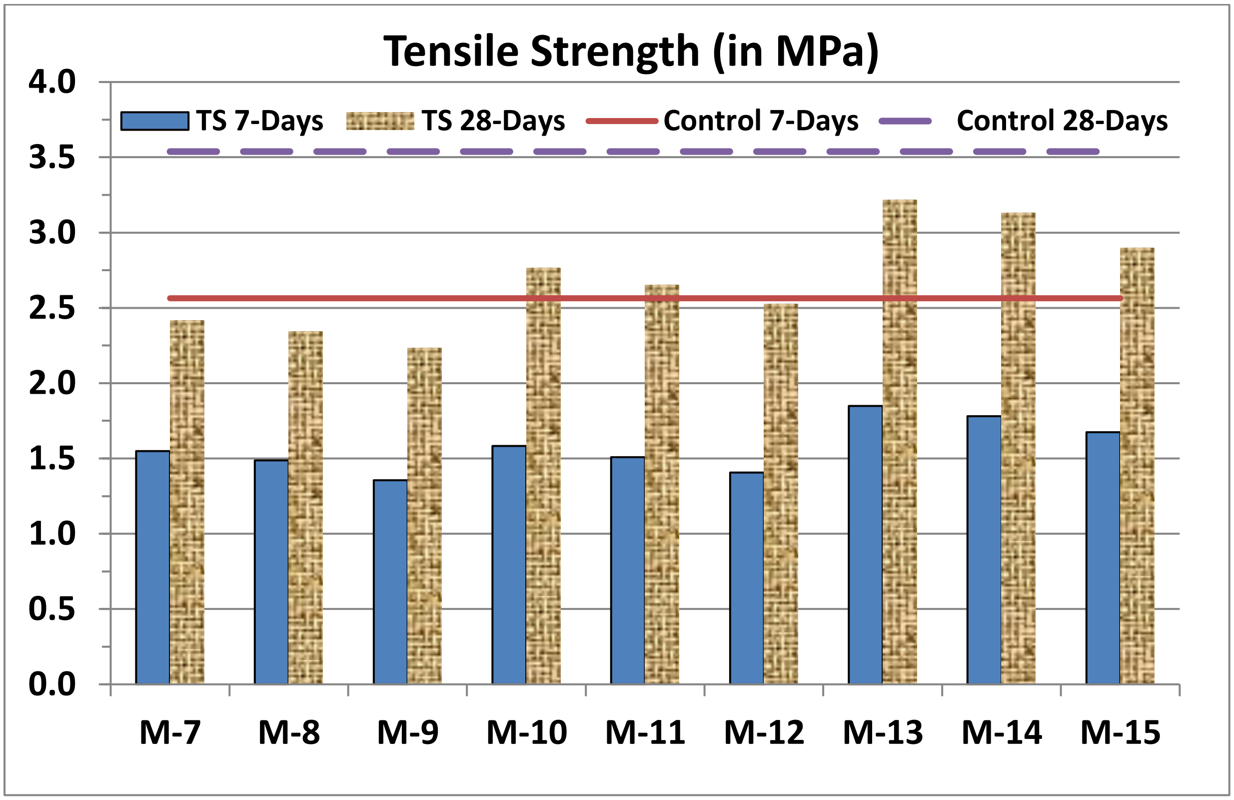

Figure 9: Tensile strength of Concrete1by using Copper Slag and Recycled Aggregates at Different Proportions

Similar to compressive strength, all the concrete mixes show low tensile strength values at early ages (7-days). Subsequently, it rapidly gains the tensile strength at the curing age of 28-days but still lower than the tensile strength of control concrete mix (M-0). Figure 10 and Figure 11 depicts the combined effect of CS and RCA on the tensile strength of concrete after 7-days and 28-days of curing, respectively. Figure 10 depicts the variation in tensile strength of designed concrete mixes with percentage variations in CS and RCA after 7-days of curing. There observed a sharp increase in strength for CS beyond 15% and decrease in strength for RCA beyond 20%. For tensile strength after 28-days of curing, the trend is similar but with a more sharp rise. This may be attributed to the combined effect of cement hydration (early-stage i.e. 7-days) and pozzolanic reaction (later stage i.e. 28 days). It discloses the fact that the effect of pozzolanic reaction on the strength development is relatively more than hydration during the curing period of 7–28 days. The values average tensile strength are within the permissible values for all the design mixes as per the IS standard. As per the designed specification tensile strength should be 0.45 times square root of compressive strength at 28 days i.e 2.25 MPa for the present study. These observations again confirmed the findings reported by Al-Jabri et al. (2009).

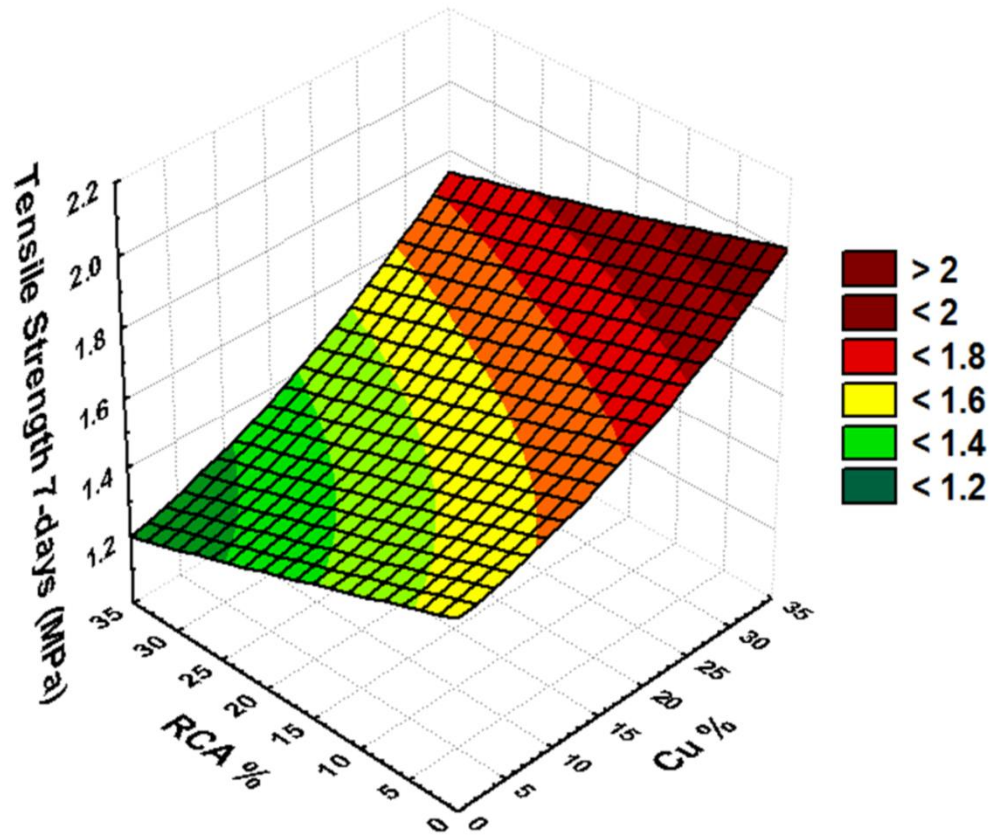

Figure 10: Impact on Tensile strength (7-days) of Concrete at varying proportions of Copper Slag and Recycled Aggregates

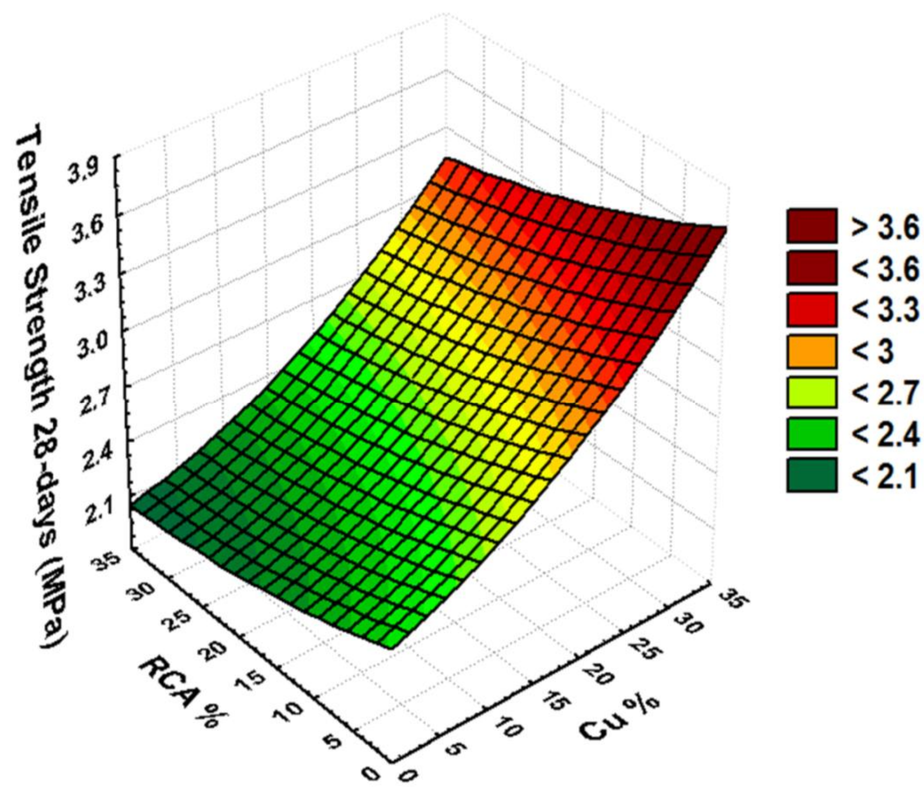

Figure 11: Impact on Tensile strength (28-days) of Concrete at varying proportions of Copper Slag and Recycled Aggregates

Figure 10 and Figure 11 reveal that for a given percentage of replacement of fine aggregate with CS, the value of compressive strength of the concrete design mix decrease with the increase in the percentage of RCA. The above observations are supported by the work of other researchers who studied the influence of copper slag as fine and coarse aggregates on the tensile strength of concrete. The results showed that the tensile strengths of concrete made with copper slag are almost the same as that of control concrete but still lower than the control mixtures (Khanzadi and Behnood 2009).

The above observation discloses the fact that for a concrete mix with both CS and RCA, a high percentage of CS is the more decisive factor for getting the higher compressive strength. The reason for the increase in tensile strength with the increasing percentage of CS may be attributed to pozzolanic and cementitious properties CS. On the other hand, the reduced tensile strength of concrete mixed with rising RCA percentage could be attributed to presence void and air which later on occupied by water during curing and also weak bonding because of the presence of adhered mortar in recycled aggregate (RCA).

4. CONCLUSION

The current study examined the usability of copper slag and recycled concrete aggregate as a replacement to sand and natural coarse aggregate respectively in designing M25 concrete is highly appealing and concurrent one. The results of the study substantiate the facts that both CS and RCA can be used effectively in preparing a concrete mix for specific applications. The results reveal that although in all the concrete mixes the workability values are within the permissible range; it is directly depended on the percentage of RCA while it is inversely proportional to the percentage of CS. The compressive strength1of concrete increases with the increasing percentage of CS while it decreases with the increasing percentage of RCA. Except for a few concrete mix samples (M-4, M-5, M-6 and M-9), the studied samples achieved the compressive strength more than the designated strength after 28-days of curing. The split1tensile strength1of concrete decreases in all the samples with CS and/or RCA compared to the control sample, though the values of tensile strength improve with the increasing percentage of CS. with respect by adding copper slag. The optimum percentage of Copper slag is 30% and 10% for recycled coarse aggregates in terms of both compressive and tensile strength. The results show that the designed mixes can be used for on-site work and for structures that need not be un-shuttered quickly. However, it is also realized that the replacement of aggregate by waste materials beyond 30% and other tests on concrete including micro-structural variation can provide additional insights on the effect of CS and RCA on the properties of concrete mix. It is expected that the outcomes and findings of the study will help civil and construction engineers to design concrete of definite grade using waste materials, especially copper slag and recycled concrete aggregates. The study ensures manifold advantages in terms of scientific advancement, making the concrete more economical and environmentally benign.

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